Source-receptor Relationships for Integrated Assessment Modelling.

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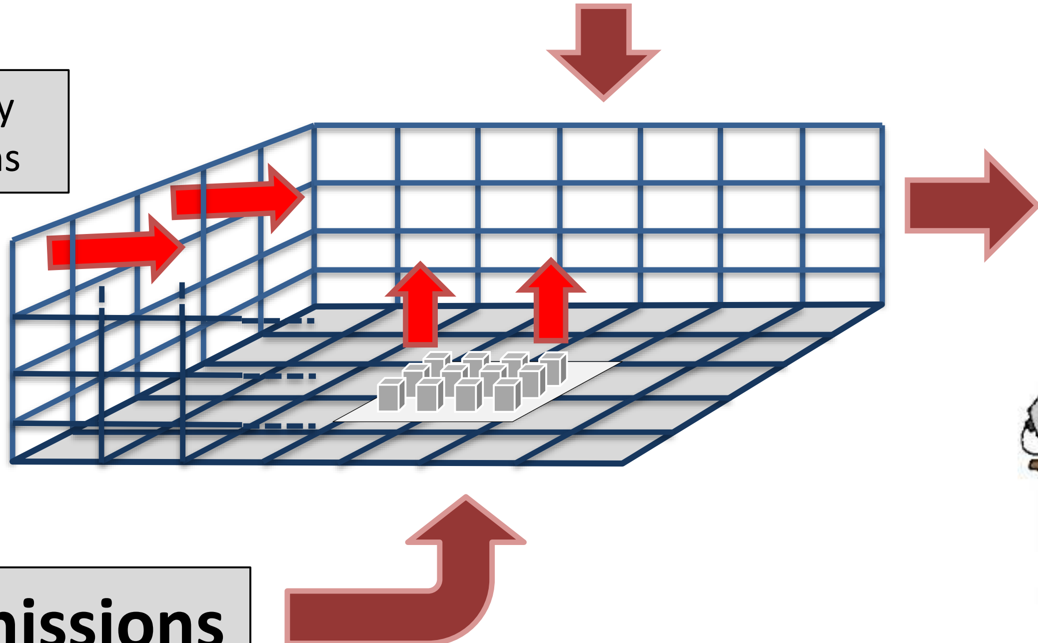
Air Quality Models

Meteorological conditions:
Wind, Temperature, Solar radiation

Boundary conditions



Concentrations

Emissions

CPU time: **days** to simulate 1 year

Source/Receptor Relationship

Specific set of emission reduction scenario simulated by an Air Quality Model

Algebraic relation between the emissions of every cell and the concentration of every cell

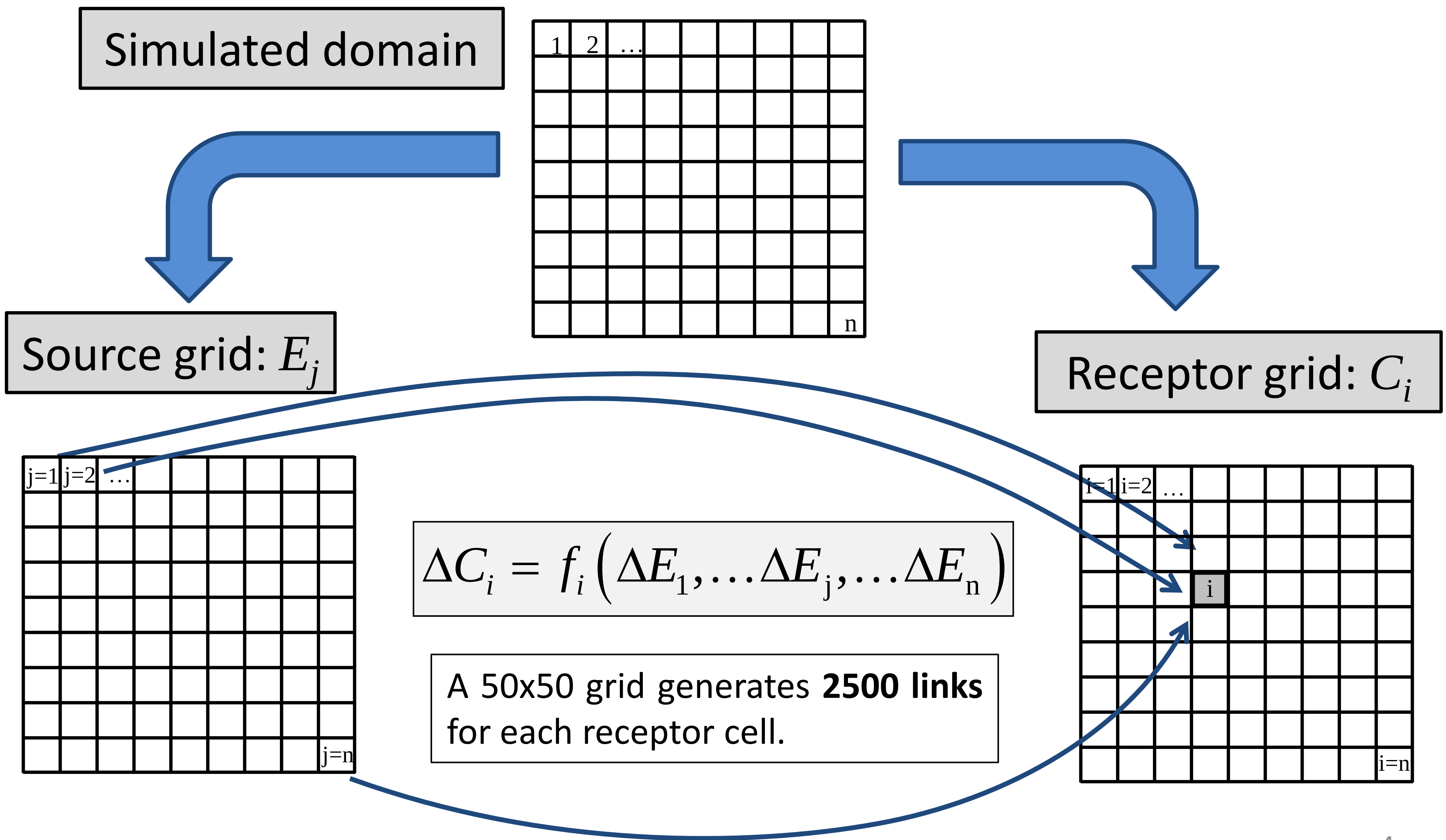
$$C_i = f_i\left(E_1, E_2, \ldots E_n\right)$$

Concentrations

Emissions

CPU time: **seconds** to simulate 1 year

Source/Receptor Relationship

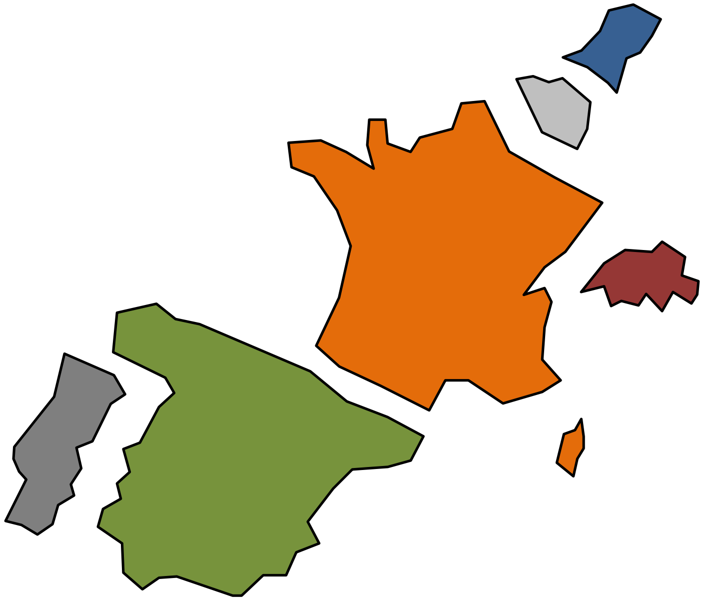


$$\Delta C_i = f_i\left(\Delta E_1, \ldots \Delta E_j, \ldots \Delta E_n\right)$$

A 50x50 grid generates **2500 links** for each receptor cell.

Integrated Assessment Models

GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) have been developed by IIASA (International Institute for Applied Systems Analysis) in order to estimate the best abatement strategies **for different countries**.

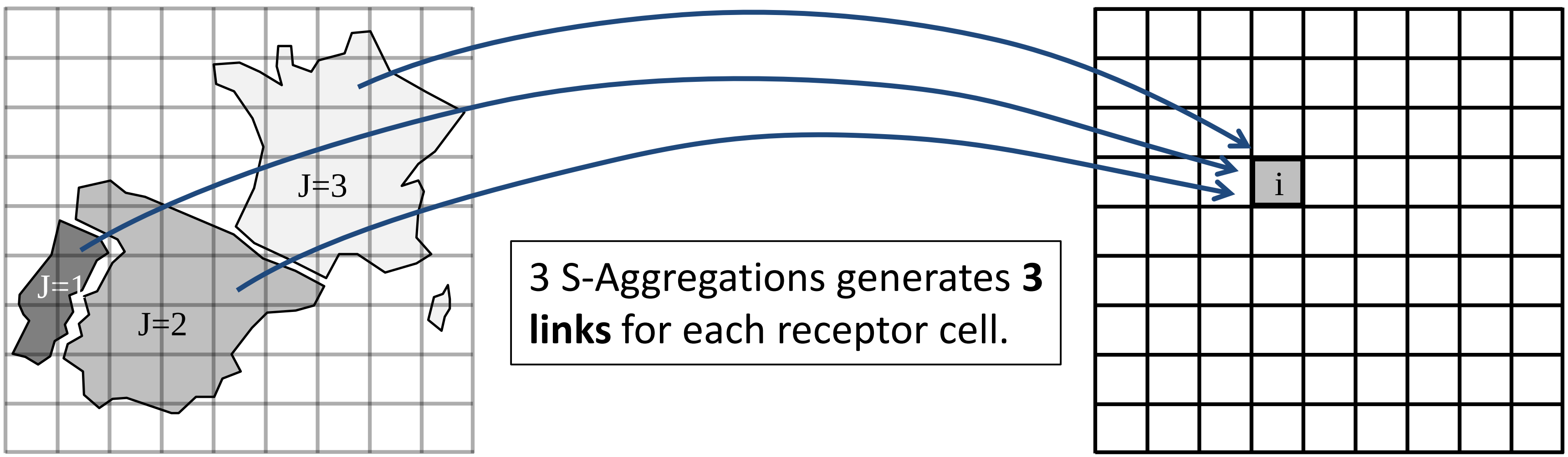


S/R Relationship in GAINS: approximation

Source grid → S-Aggregation

$$\bar{E}_J = \sum_j E_j$$

Receptor grid



3 S-Aggregations generates **3 links** for each receptor cell.

Linear approximation:

Example for 3 countries: $\Delta C_i = a_i^{\mathrm{Po}} \Delta \bar{E}_{\mathrm{Po}} + a_i^{\mathrm{Sp}} \Delta \bar{E}_{\mathrm{Sp}} + a_i^{\mathrm{Fr}} \Delta \bar{E}_{\mathrm{Fr}}$

S/R Relationship in GAINS: methodology

Linear approximation:

Example for 3 countries: $$\boxed{\Delta C_i = a_i^{\mathrm{Po}} \Delta \bar{E}_{\mathrm{Po}} + a_i^{\mathrm{Sp}} \Delta \bar{E}_{\mathrm{Sp}} + a_i^{\mathrm{Fr}} \Delta \bar{E}_{\mathrm{Fr}}}$$

Then, 3 scenario runs are needed to estimate the 3 coefficients for 3 countries:

	Po	Sp	Fr
Sc1	$\Delta \bar{E}_{\mathrm{Po}}^{\mathrm{Sc1}}$	0	0
Sc2	0	$\Delta \bar{E}_{\mathrm{Sp}}^{\mathrm{Sc2}}$	0
Sc3	0	0	$\Delta \bar{E}_{\mathrm{Fr}}^{\mathrm{Sc3}}$

$\Rightarrow$

$$a_i^{\mathrm{Po}} \Delta \bar{E}_{\mathrm{Po}}^{\mathrm{Sc1}} + a_i^{\mathrm{Sp}} \times 0 + a_i^{\mathrm{Fr}} \times 0 = \Delta C_i^{\mathrm{Sc1}}$$
$$a_i^{\mathrm{Po}} \times 0 + a_i^{\mathrm{Sp}} \Delta \bar{E}_{\mathrm{Sp}}^{\mathrm{Sc2}} + a_i^{\mathrm{Fr}} \times 0 = \Delta C_i^{\mathrm{Sc2}}$$
$$a_i^{\mathrm{Po}} \times 0 + a_i^{\mathrm{Sp}} \times 0 + a_i^{\mathrm{Fr}} \Delta \bar{E}_{\mathrm{Fr}}^{\mathrm{Sc3}} = \Delta C_i^{\mathrm{Sc3}}$$

$\Rightarrow$

$$a_i^{\mathrm{Po}} = \Delta C_i^{\mathrm{Sc1}} / \Delta \bar{E}_{\mathrm{Po}}^{\mathrm{Sc1}}$$
$$a_i^{\mathrm{Sp}} = \Delta C_i^{\mathrm{Sc2}} / \Delta \bar{E}_{\mathrm{Sp}}^{\mathrm{Sc2}}$$
$$a_i^{\mathrm{Fr}} = \Delta C_i^{\mathrm{Sc3}} / \Delta \bar{E}_{\mathrm{Fr}}^{\mathrm{Sc3}}$$

S/R Relationship in GAINS: weaknesses

Number of scenario run:

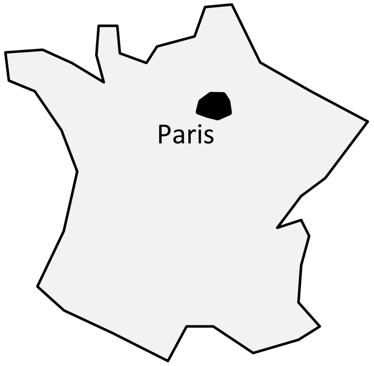
In fact the pollutant concentrations depends from different several precursors which are emitted. For example, PM concentrations depends from 5 precursors (each precursors being emitted by countries).

$$\Delta C_{i,\mathrm{PM}} = a_{i,\mathrm{NO_x}}^{\mathrm{Po}} \Delta E_{\mathrm{NO_x}}^{\mathrm{Po}} + a_{i,\mathrm{NH_3}}^{\mathrm{Po}} \Delta E_{\mathrm{NH_3}}^{\mathrm{Po}} + a_{i,\mathrm{VOC}}^{\mathrm{Po}} \Delta E_{\mathrm{VOC}}^{\mathrm{Po}} + a_{i,\mathrm{SO_2}}^{\mathrm{Po}} \Delta E_{i,\mathrm{SO_2}}^{\mathrm{Po}} + a_{i,\mathrm{PPM}}^{\mathrm{Po}} \Delta E_{\mathrm{PPM}}^{\mathrm{Po}} + a_{i,\mathrm{NO_x}}^{\mathrm{Sp}} \Delta E_{\mathrm{NO_x}}^{\mathrm{Sp}} + \ldots$$

So that in Europe, for 30 countries and 5 precursors, **150 scenario runs** are needed to calculate the 150 coefficients (30 × 5) which requires around **1 month CPU time**.

S-Aggregations resolution:

The effect of punctual sources is diluted into the entire country (Example Paris in France). Improving the resolution requires a division into more regions which lead to more scenarios. The division of Europe in region instead of countries would requires **300 scenario runs** (i.e. **40 months CPU time**).



S/R Relationship in GAINS: weaknesses

No robustness estimation:

The 3 coefficients of 3 countries can be found solving a system of 3 equations and 3 unknowns provided by 3 abatement scenarios. A very large number of scenario combination can be used:

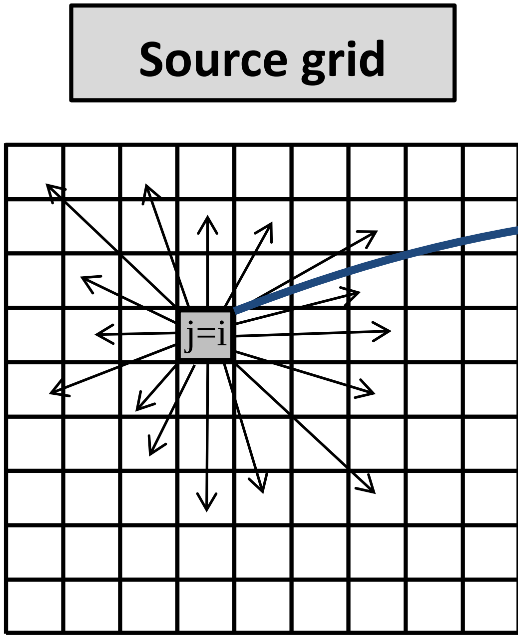
	Po	Sp	Fr
Sc1	$\Delta\bar{E}_{\mathrm{Po}}^{\mathrm{Sc1}}$	$\Delta\bar{E}_{\mathrm{Sp}}^{\mathrm{Sc1}}$	$\Delta\bar{E}_{\mathrm{Fr}}^{\mathrm{Sc1}}$
Sc2	$\Delta\bar{E}_{\mathrm{Po}}^{\mathrm{Sc2}}$	$\Delta\bar{E}_{\mathrm{Sp}}^{\mathrm{Sc2}}$	$\Delta\bar{E}_{\mathrm{Fr}}^{\mathrm{Sc2}}$
Sc3	$\Delta\bar{E}_{\mathrm{Po}}^{\mathrm{Sc3}}$	$\Delta\bar{E}_{\mathrm{Sp}}^{\mathrm{Sc3}}$	$\Delta\bar{E}_{\mathrm{Fr}}^{\mathrm{Sc3}}$

$$\Rightarrow \left.\begin{aligned}
a_i^{\mathrm{Po}}\Delta\bar{E}_{\mathrm{Po}}^{\mathrm{Sc1}} + a_i^{\mathrm{Sp}}\Delta\bar{E}_{\mathrm{Sp}}^{\mathrm{Sc1}} + a_i^{\mathrm{Fr}}\Delta\bar{E}_{\mathrm{Fr}}^{\mathrm{Sc1}} &= \Delta C_i^{\mathrm{Sc1}} \\
a_i^{\mathrm{Po}}\Delta\bar{E}_{\mathrm{Po}}^{\mathrm{Sc2}} + a_i^{\mathrm{Sp}}\Delta\bar{E}_{\mathrm{Sp}}^{\mathrm{Sc2}} + a_i^{\mathrm{Fr}}\Delta\bar{E}_{\mathrm{Fr}}^{\mathrm{Sc2}} &= \Delta C_i^{\mathrm{Sc2}} \\
a_i^{\mathrm{Po}}\Delta\bar{E}_{\mathrm{Po}}^{\mathrm{Sc3}} + a_i^{\mathrm{Sp}}\Delta\bar{E}_{\mathrm{Sp}}^{\mathrm{Sc3}} + a_i^{\mathrm{Fr}}\Delta\bar{E}_{\mathrm{Fr}}^{\mathrm{Sc3}} &= \Delta C_i^{\mathrm{Sc3}}
\end{aligned}\right\} \Rightarrow a_i^{\mathrm{Po}}, a_i^{\mathrm{Sp}}, a_i^{\mathrm{Fr}}$$

How **robust** is the coefficient estimation with regard to the set of scenario runs which can be chosen?

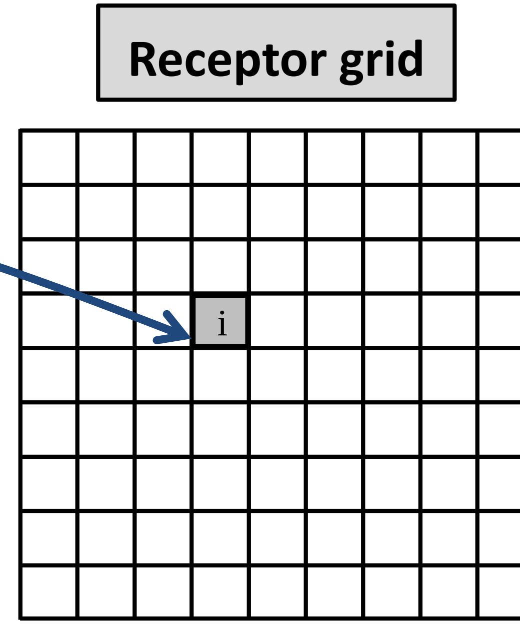
More equations than unknowns are needed to estimate and increase the robustness. With methodology the only way to add equations to the system means is to **run more scenarios**…

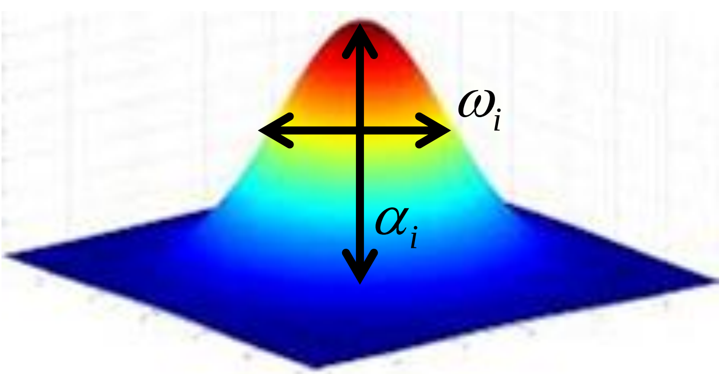
2 Steps Weighted Aggregations



For 1 precursor:

$$\Delta C_i = \alpha_i \sum_{j=1}^{n} \frac{1}{\left(1 + d_{ij}\right)^{\omega_i}} \Delta E_j$$





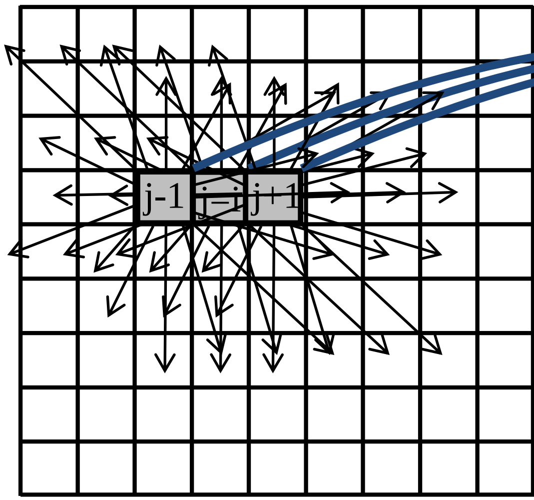
d_{ij} is the distance between the receptor i (central cell) and each source cell j.

ω_i skewness

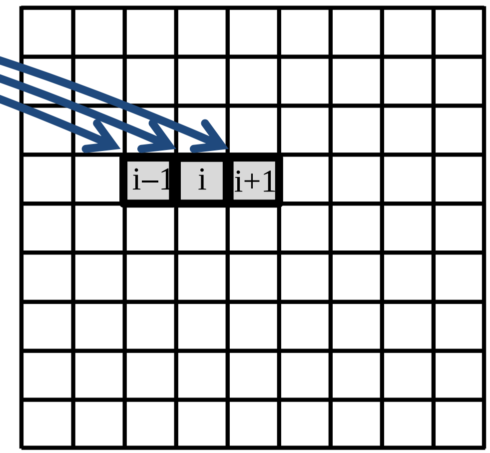
α_i amplitude

2 Steps Weighted Aggregations: Robustness

Source grid



Receptor grid → R-Aggregation



Step 1

The parameters α and ω are calculated for each precursor using **1 scenario** reducing only the emission of this precursor. parameters are considered the same for **a large set of receptor cells** in order to provide a large number of equations.

$$\vdots \qquad \vdots \qquad \vdots$$

$$\Delta C_{i-1} \qquad \Delta E_{i-1} \qquad \Delta C_{i-1} = \alpha_i \sum_{j=1}^{n} \left(1 + d_{i-1\,j-1}\right)^{-\omega_i} \Delta E_{j-1}$$

$$\Delta C_{i} \qquad \Delta E_{i} \qquad \Delta C_{i} = \alpha_i \sum_{j=1}^{n} \left(1 + d_{ij}\right)^{-\omega_i} \Delta E_{j}$$

$$\Delta C_{i+1} \qquad \Delta E_{i+1} \qquad \Delta C_{i+1} = \alpha_i \sum_{j=1}^{n} \left(1 + d_{i+1\,j+1}\right)^{-\omega_i} \Delta E_{j+1}$$

$$\vdots \qquad \vdots \qquad \vdots$$

➡ α_i and ω_i

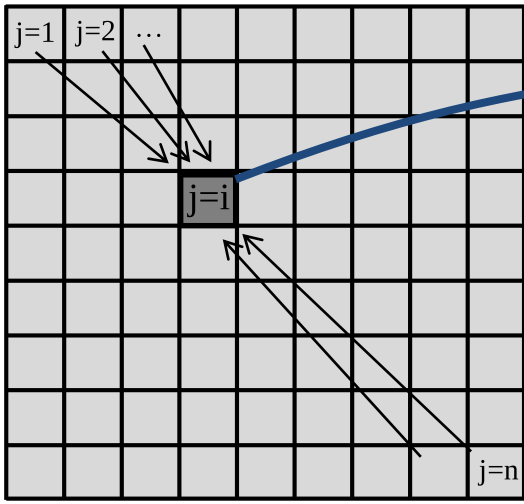
The 2 unknowns are calculated using **a large set of equations** provided by **only 1 scenario.**

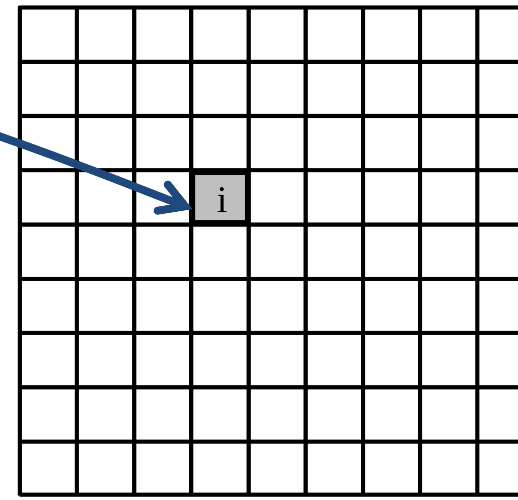
2 Steps Weighted Source Aggregation: Accuracy

Source grid → S-Aggregation

$$\Delta\overline{E}_i = \sum_{j=1}^{n} \frac{1}{\left(1+d_{ij}\right)^{\omega_i}} \Delta E_j \;\; \begin{cases} \Delta\overline{E}_{i,\mathrm{NO_x}} \\ \Delta\overline{E}_{i,\mathrm{NH_3}} \\ \vdots \end{cases}$$

Receptor grid





Step 2

The emissions of each precursor are aggregated using the parameter ω computed during step 1. The **all set scenario** (at least 6) reducing all the precursors are used to compute new values of α for all precursor on **1 receptor cell**.

$$\left.\begin{aligned}
\Delta C^{\mathrm{Sc1}}_{i,\mathrm{PM}} &= \alpha_{i,\mathrm{NO_x}} \Delta\overline{E}^{\mathrm{Sc1}}_{i,\mathrm{NO_x}} + \alpha_{i,\mathrm{NH_3}} \Delta\overline{E}^{\mathrm{Sc1}}_{i,\mathrm{NH_3}} + \alpha_{i,\mathrm{VOC}} \Delta\overline{E}^{\mathrm{Sc1}}_{i,\mathrm{VOC}} + \alpha_{i,\mathrm{SO_2}} \Delta\overline{E}^{\mathrm{Sc1}}_{i,\mathrm{SO_2}} + \alpha_{i,\mathrm{PPM}} \Delta\overline{E}^{\mathrm{Sc1}}_{i,\mathrm{PPM}} \\
\Delta C^{\mathrm{Sc2}}_{i,\mathrm{PM}} &= \alpha_{i,\mathrm{NO_x}} \Delta\overline{E}^{\mathrm{Sc2}}_{i,\mathrm{NO_x}} + \alpha_{i,\mathrm{NH_3}} \Delta\overline{E}^{\mathrm{Sc2}}_{i,\mathrm{NH_3}} + \alpha_{i,\mathrm{VOC}} \Delta\overline{E}^{\mathrm{Sc2}}_{i,\mathrm{VOC}} + \alpha_{i,\mathrm{SO_2}} \Delta\overline{E}^{\mathrm{Sc2}}_{i,\mathrm{SO_2}} + \alpha_{i,\mathrm{PPM}} \Delta\overline{E}^{\mathrm{Sc2}}_{i,\mathrm{PPM}} \\
\vdots \quad & \quad \vdots \qquad\quad \vdots \qquad\qquad \vdots \qquad\qquad \vdots \qquad\qquad \vdots
\end{aligned}\right\} \Rightarrow$$

$$\alpha_{i,\mathrm{NO_x}}, \alpha_{i,\mathrm{NH_3}}, \alpha_{i,\mathrm{VOC}}, \alpha_{i,\mathrm{SO_2}}, \alpha_{i,\mathrm{PPM}}$$

5 unknowns are calculated on **1 receptor cell** using at least 6 equations.

2 Steps Weighted Source Aggregation: Overview

Step 1

The parameters α and ω are calculated for each precursors using 1 scenario run and large aggregation of source cells to improve robustness..

$$\Delta C_{i,\mathrm{PM}}^{Sc1} = \alpha'_{i,\mathrm{NO_x}} \sum_{j=1}^{n} \left(1+d_{ij}\right)^{-\omega_{i,\mathrm{NO_x}}} \Delta E_{j,\mathrm{NO_x}}$$

$$\Delta C_{i,\mathrm{PM}}^{Sc2} = \alpha'_{i,\mathrm{NH_3}} \sum_{j=1}^{n} \left(1+d_{ij}\right)^{-\omega_{i,\mathrm{NH_3}}} \Delta E_{j,\mathrm{NH_3}}$$

$$\vdots \qquad \vdots$$

Step 2

The parameter ω computed in step 1 are used aggregate the emission:

$$\Delta \overline{E}_{i,\mathrm{NO_x}} = \sum_{j=1}^{n} \left(1+d_{ij}\right)^{-\omega_{i,\mathrm{NO_x}}} \Delta E_{j,\mathrm{NO_x}}$$

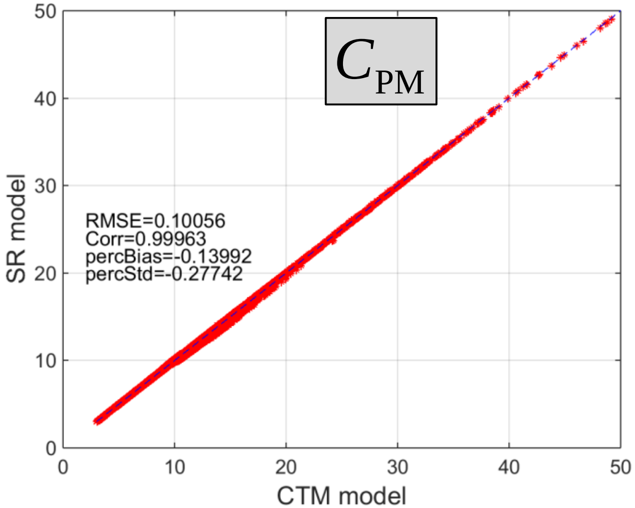
$$\Delta \overline{E}_{i,\mathrm{NH_3}} = \sum_{j=1}^{n} \left(1+d_{ij}\right)^{-\omega_{i,\mathrm{NH_3}}} \Delta E_{j,\mathrm{NH_3}}$$

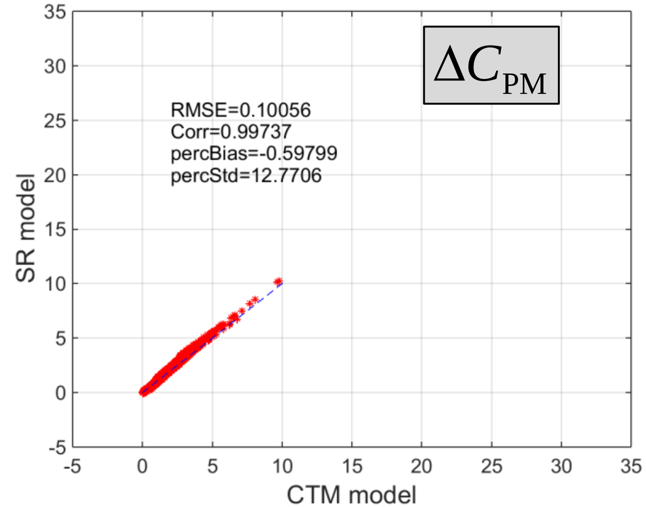
$$\vdots \qquad \vdots$$

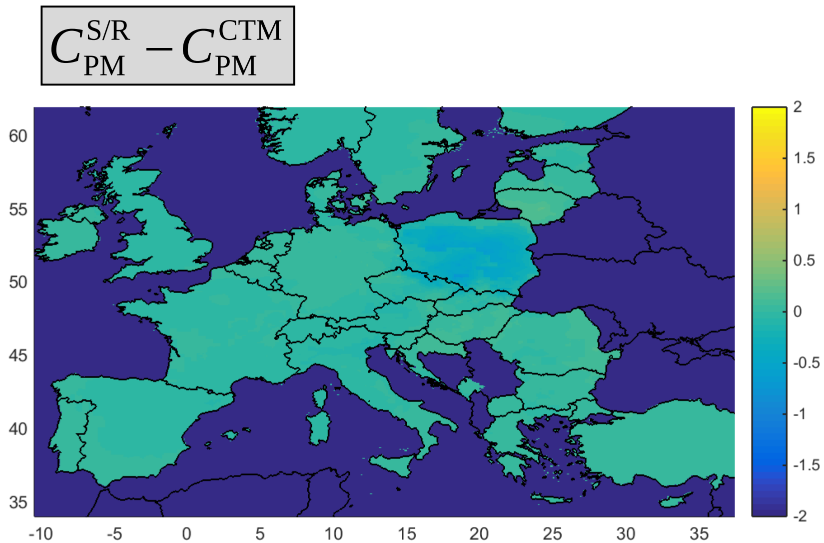
The parameters α are re-computed using the all set of scenarios and only 1 receptor to improve accuracy.

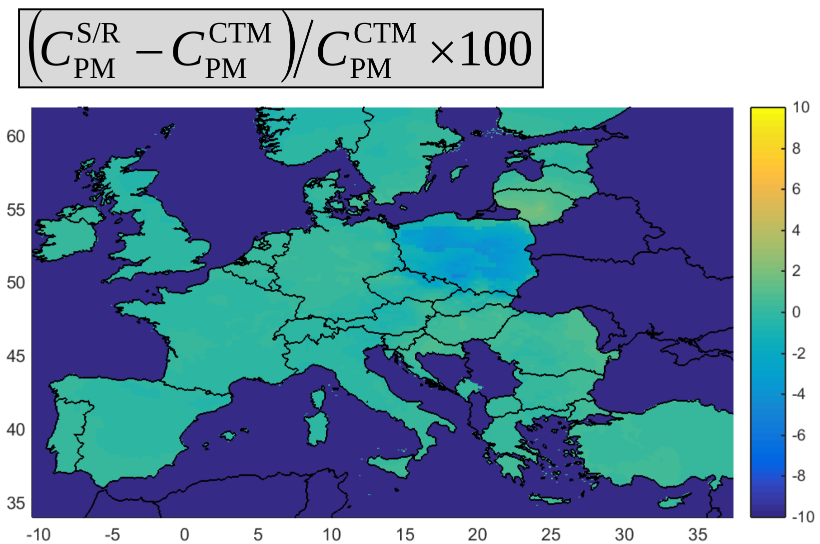
$$\Delta C_{i,\mathrm{PM}} = \alpha_{i,\mathrm{NO_x}} \Delta \overline{E}_{i,\mathrm{NO_x}} + \alpha_{i,\mathrm{NH_3}} \Delta \overline{E}_{i,\mathrm{NH_3}} + \alpha_{i,\mathrm{VOC}} \Delta \overline{E}_{i,\mathrm{VOC}} + \alpha_{i,\mathrm{SO_2}} \Delta \overline{E}_{i,\mathrm{SO_2}} + \alpha_{i,\mathrm{PPM}} \Delta \overline{E}_{i,\mathrm{PPM}}$$

Validation: Reduction over Poland



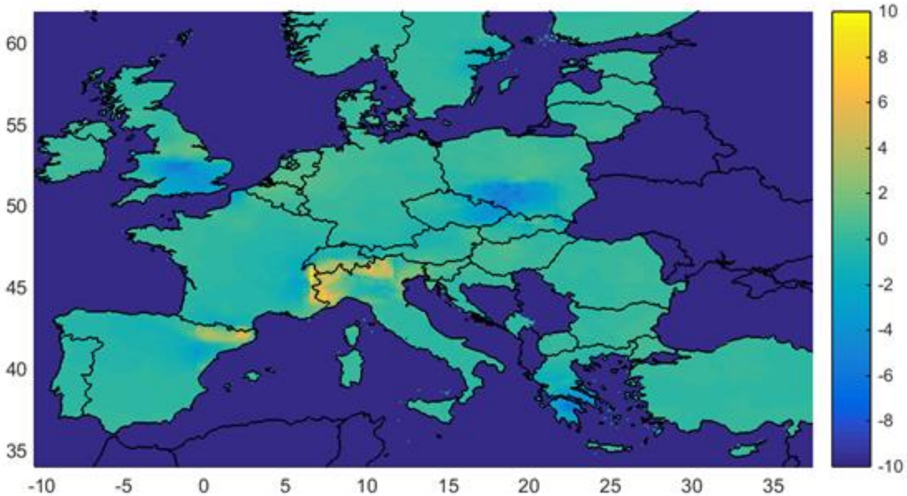




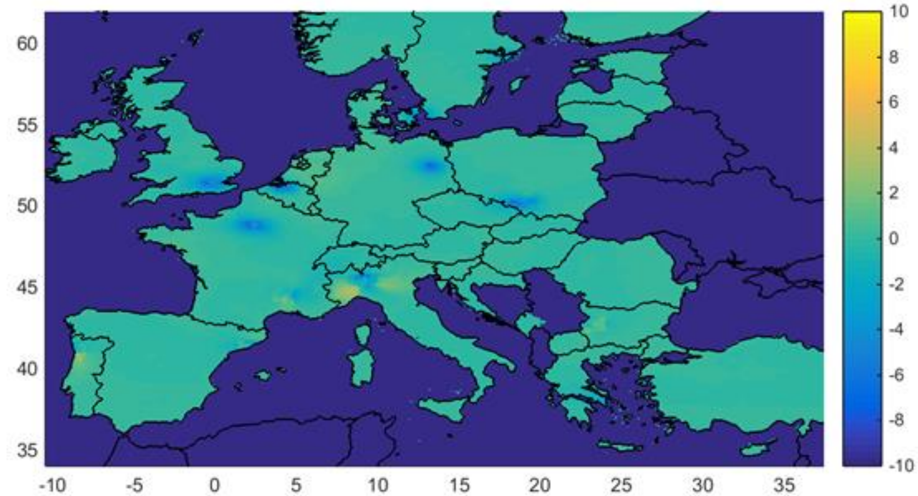


Validation: Reduction over small regions

$$\left(C_{\mathrm{PM}}^{\mathrm{S/R}} - C_{\mathrm{PM}}^{\mathrm{CTM}}\right) / C_{\mathrm{PM}}^{\mathrm{CTM}} \times 100$$



Emission reduction over 140x140 km squares centered on Katovice, Lombardy, London, Barcelona, Athens, Stockholm



Emission reduction over 35x35 km squares centered on Katovice, Lombardy, London, Barcelona, Athens, Stockholm, Antwerp, Porto, Paris, Rocher, Berlin, Copenhagen, Sofia


どうもありがとうございます